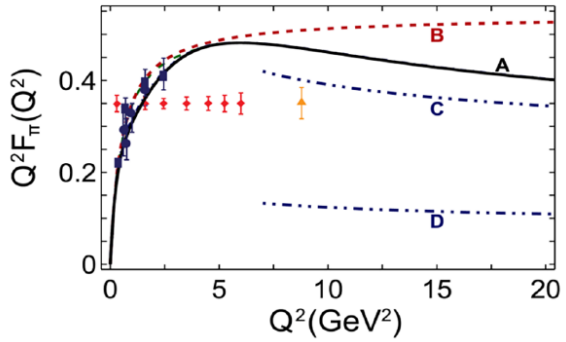
Light Meson Structure Programs at JLab and EIC

Beyond protons and neutrons, pions and kaons are the necessary main building blocks of nuclear matter.
If we really want to claim we understand QCD dynamics, we have to understand their structure.

2015 NSAC Long-Range Plan Highlight: pion form factor



Phenomenology of QCD begins to transition from large- to short-distance-scale behavior – strong synergy between experiments, phenomenology, and LQCD

PionLT Publications – based on two 6 GeV pion experiments

~2000

6 GeV Pion Experiments:
1997 (phase 1)
2003 (phase 2)

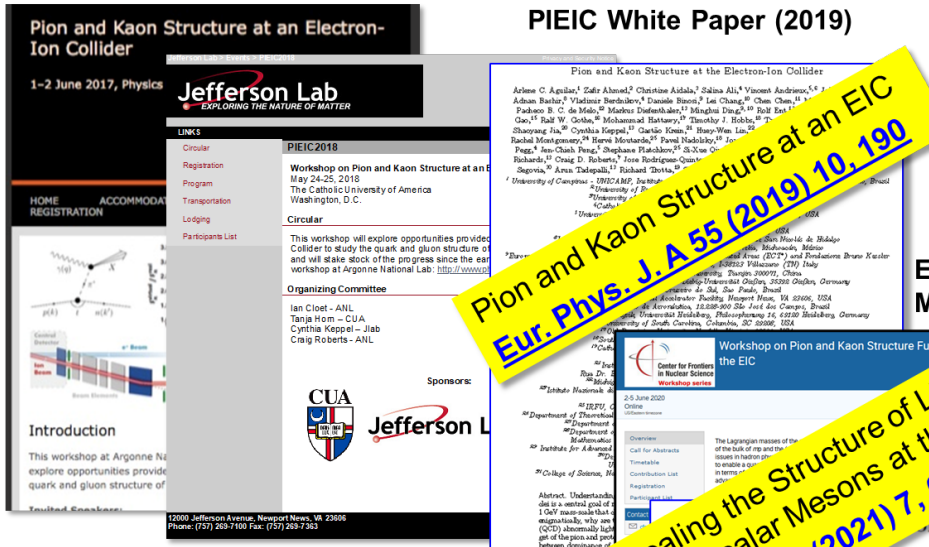
- J. Volmer, et al., Phys. Rev. Lett. **86** (2001) 1713 – **319 citations**
  - Precision F_π results between Q^2=0.60 and 1.60 GeV^2
- T. Horn, D. Gaskell, G. Huber, et al., Phys. Rev. Lett. **97** (2006) 192001 – **255 citations**
  - Precision F_π results at Q^2=1.60 and 2.45 GeV^2
- V. Tadevosyan, et al., Phys. Rev. C**75** (2007) 055205 – **212 citations**
- G. Huber, T. Horn, D. Gaskell, et al., Phys. Rev. C**78** (2008) 045203 – **194 citations**
  - Archival paper of precision F_π measurements at JLab 6 GeV
- H. P. Blok, T. Horn, G. Huber, et al., Phys. Rev. C**78** (2008) 045202 – **112 citations**
  - Archival paper of precision LT separated pion cross sections at JLab 6 GeV
- T. Horn, D. Gaskell, G. Huber, et al., Phys. Rev. C**78** (2008) 058201 – **73 citations**
  - L/T cross sections and F_π at Q^2=2.15 GeV^2 ,exploratory at Q^2~4.0 GeV^2
- Plus several spin-off papers on, e.g. L/T separations in π^- and ω production, high-t, transverse charge density (2012-present)

2020

- **Flagship measurements for hadron structure studies – highly cited**
- **Two recent JLab@12 GeV experiments successfully completed 2018-2022**
- **A key science driver for higher energy JLab and EIC**

Pion and Kaon Structure at the EIC – History

- PIEIC Workshops hosted at ANL (2017) and CUA (2018)
- ECT* Workshop: Emergent Mass and its Consequences (2018)



PIEIC White Paper (2019)

Pion and Kaon Structure at an EIC
Eur. Phys. J. A 55 (2019) 10, 190

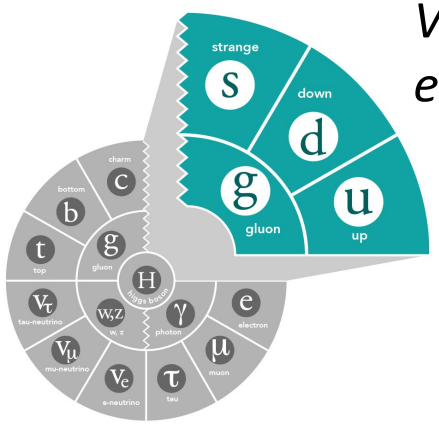
EIC Yellow Report and Meson SF Paper (2021)

Revealing the Structure of Light Pseudoscalar Mesons at the EIC
J. Phys. G 48 (2021) 7, 075106

- AMBER/CERN Workshop (2020)
- CFNS Workshop (2020)
- EHM through AMBER@CERN (2020)
- ECT* Workshop in 2021 (remote) & 2022 (hybrid

Paradoxically, the lightest pseudoscalar mesons – the pions and kaons – appear to be key to the further understanding of the emergent mass and structure mechanisms.

Understanding Light Mesons is Vital for Hadron Structure



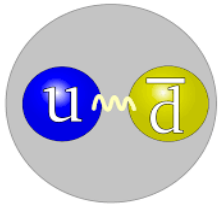
Visible world: mainly made of light quarks – its mass emerges from quark-gluon interactions.

Proton

Quark structure: uud
Mass ~ 940 MeV (~1 GeV)
Most of mass generated by dynamics.
Gluon rise discovered by HERA e-p

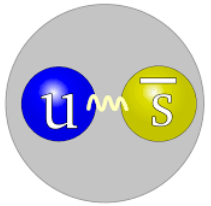
Pion

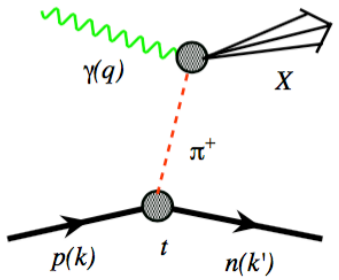
Quark structure: ud
Mass ~ 140 MeV
Exists only if mass is dynamically generated.
Empty or full of gluons?



Kaon

Quark structure: us
Mass ~ 490 MeV
Boundary between emergent- and Higgs-mass mechanisms.
More or less gluons than in pion?





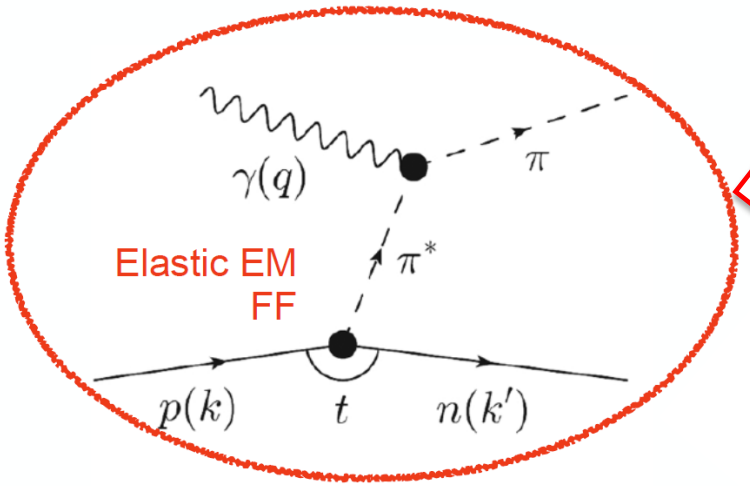
Understanding pion/kaon is vital to our understanding of hadron structure and dynamic generation of hadron mass

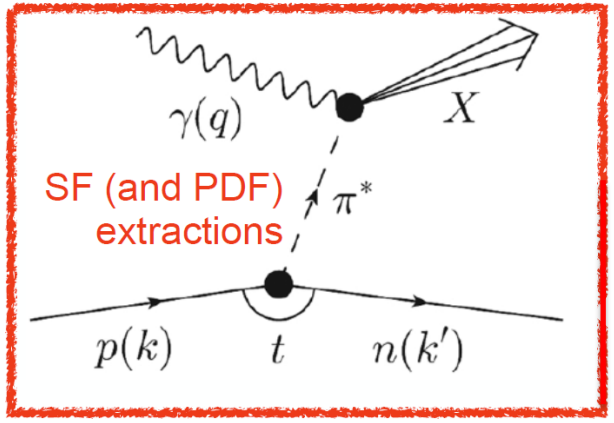
*A.C. Aguilar et al., Pion and Kaon structure at the EIC, EPJA **55 (2019)** 190.*
*J. Arrington et al., Revealing the structure of light pseudoscalar mesons at the EIC, J. Phys. G **48 (2021)** 7 075106.*
*C.D. Roberts, D. Richards, T. Horn, L. Chang, Insights into Emergence of Mass, Prog. Part. NP **120 (2021)** 103883*

Pion/Kaon Structure at Jefferson Lab 12 GeV+ and EIC

Sullivan

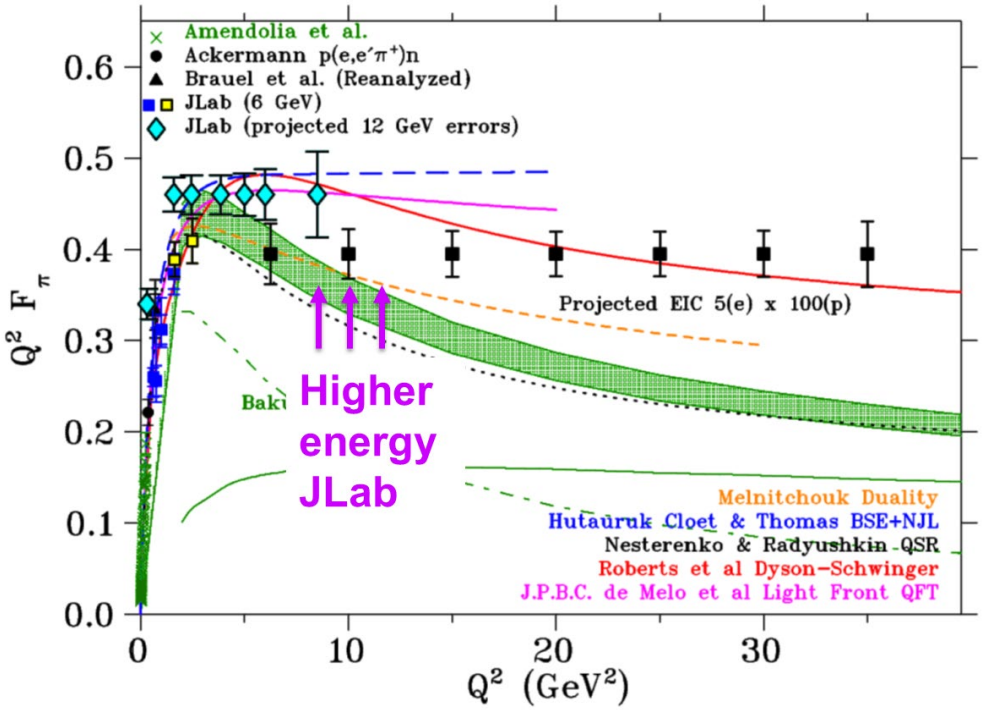
Hard scattering from virtual meson cloud of nucleon





Pion/Kaon elastic EM Form Factor

- Informs how emergent mass manifests in the wave function



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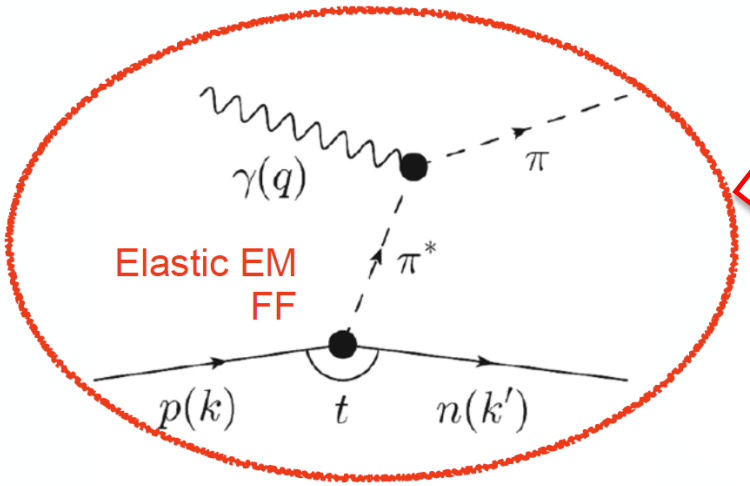

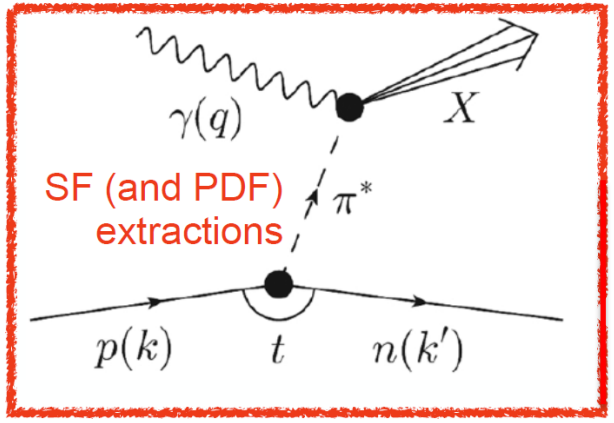

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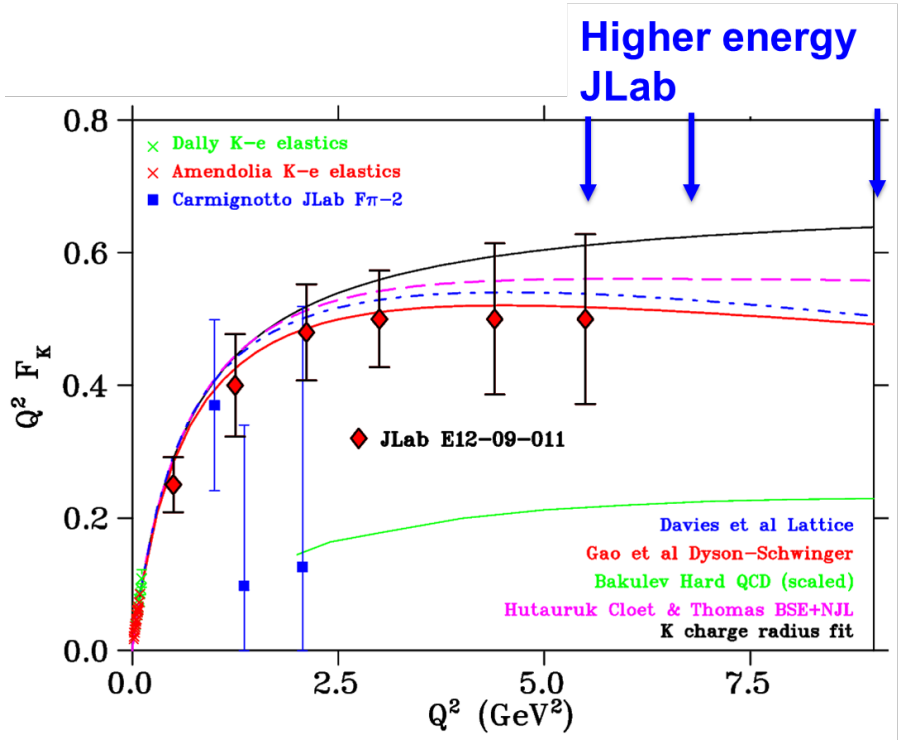

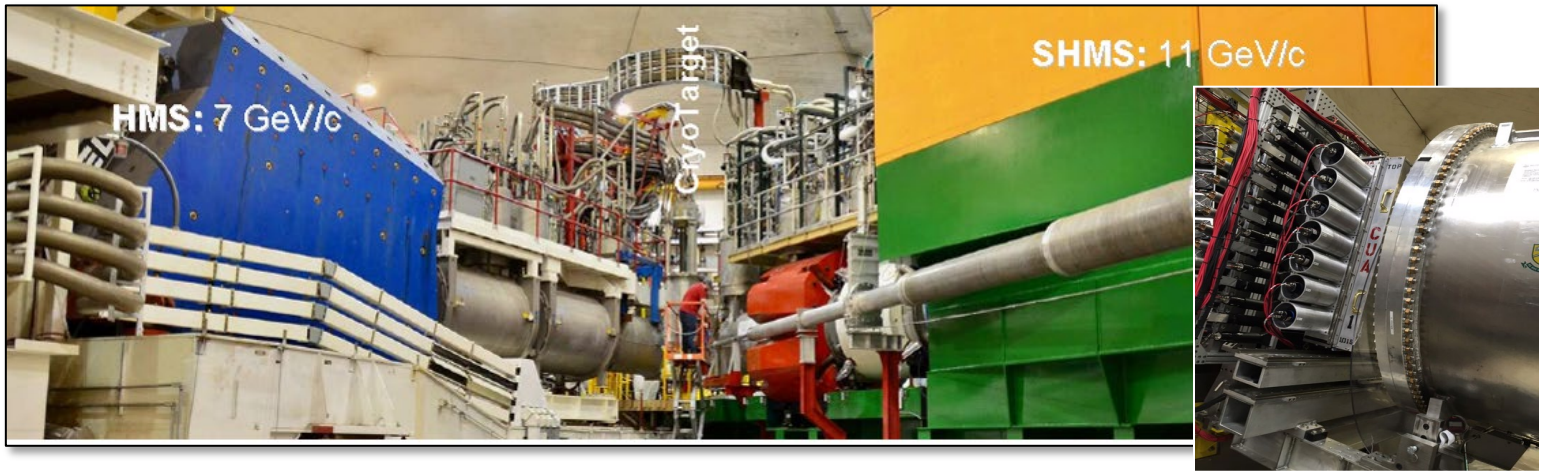

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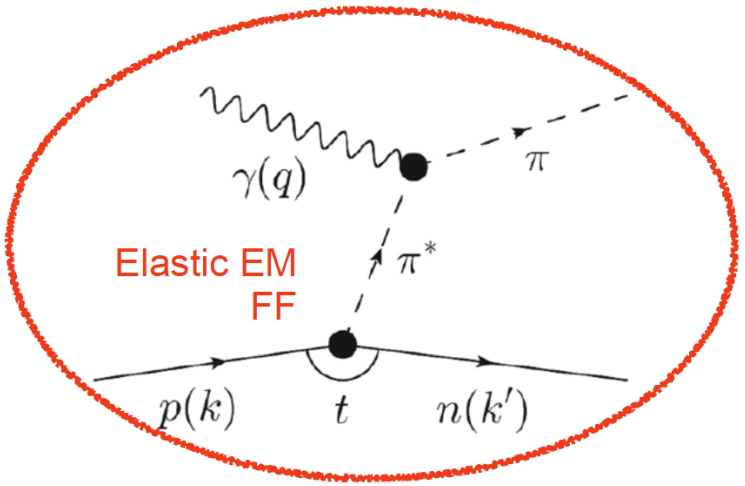
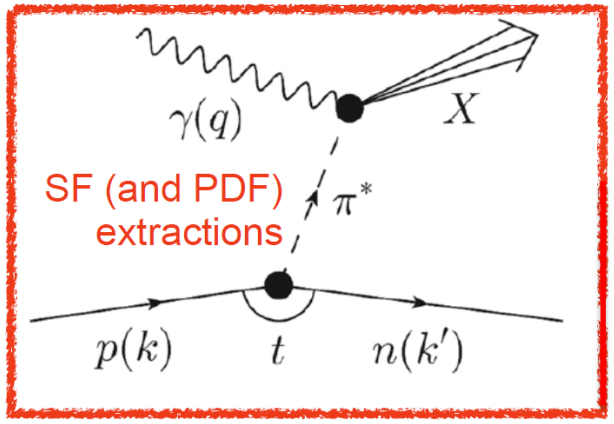
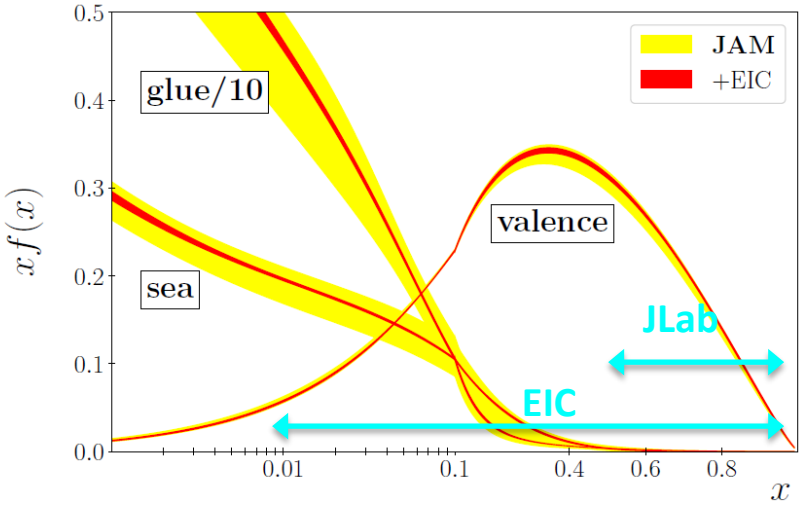
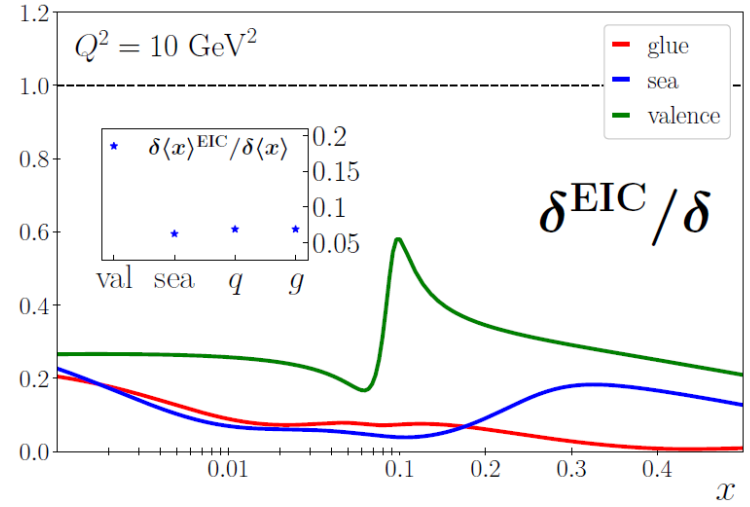




EIC Projections – large reduction of uncertainties of pion pdfs!

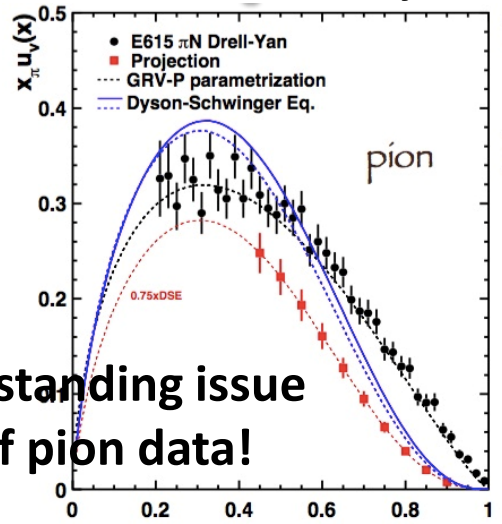


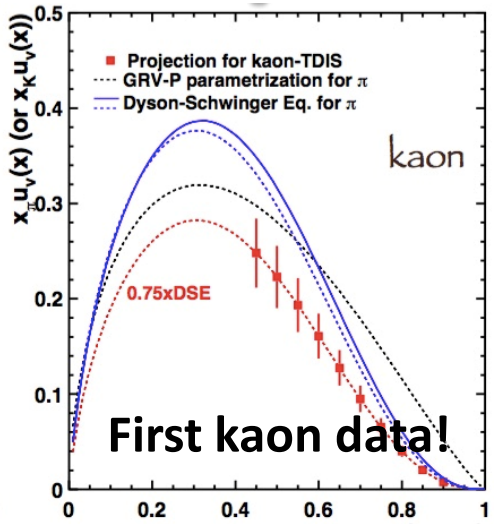


Pion/Kaon Structure Functions

Informs about the quark-gluon momentum fractions

JLab 12 GeV Projections





Solve longstanding issue of shape of pion data!

First kaon data!

Light Meson Structure Programs at JLab and EIC

- The questions of how the bulk of the Universe's visible mass emerges and how it is manifest in the existence and properties of hadrons is a central problem in nuclear physics.
- Paradoxically, the lightest pseudoscalar mesons (pions and kaons) are key to a further understanding of the emergent mass and structure mechanisms.
- As such, the experimental investigation of the structures of these particles (pion and kaon form factors and structure functions) is a key science driver for higher energy JLab and EIC.